IGFC
(EAGLE PROJECT)

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Abstract

High-efficiency direct power generation technologies, such as molten carbonate fuel cells (MCFCs) and solid oxide fuel cells (SOFCs) are expected to advance into practical use in the 21st century. To take advantage of coal as a fuel-cell fuel, coal should be supplied after being converted to gas. Oxygen-blown entrained bed gasification is regarded as optimum due to the high concentrations of carbon dioxide and hydrogen as a combustible and the high per-unit calorific value of coal gas. The objectives of our project "EAGLE" are to develop optimum coal gasifier for fuel cells and to establish a clean-up system which purifies the gas to a level acceptable for fuel cells. A feasibility study of integrated coal gasification fuel cell combined cycle (IGFC) was conducted in fiscal year 1995, supporting tests to obtain data necessary for coal gasifier design in fiscal year 1995-1996, and basic and detail design of a pilot plant for processing 150 tons of coal per day in fiscal year 1996-1997. The construction work was started at the test site, the Wakamatsu Operations & General Management Office, and to manufacture the gasifier and other main facilities were also started in 1998. Operation is scheduled to commence in fiscal year 2001. This paper describes the performance of IGFC using MCFC and the status of the pilot plant.

IGFC (EAGLE Project)

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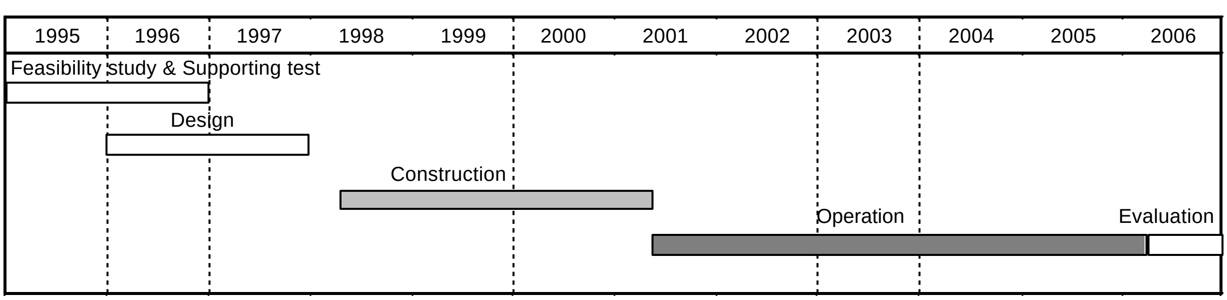
1. Introduction

Development of high efficiency direct power generation technologies, such as molten carbonate fuel cells (MCFC) and solid oxide fuel cells (SOFC), is currently being promoted since they are expected to become next-generation power generating technologies. Meanwhile, coal is also expected to become a more important energy resource since it has abundant reserves that are more evenly distributed territorially than those of other energy resources. The ash contained in the coal is the greatest obstacle when coal is used in fuel cells. Thus the coal must be supplied to fuel cells after converting it into an ash-free fuel gas. The objectives of this project are to develop an optimum coal gasifier for fuel cells and to establish a clean-up system which purifies the gas to a level acceptable for fuel cells. Table 1 shows the development schedule. A feasibility study of the integrated coal gasification fuel cell combined cycle (IGFC) was conducted in fiscal year 1995, supporting tests to obtain data necessary for coal gasifier design in fiscal years 1995 - 1996, and basic and detail design of a pilot plant for processing 150 tons of coal per day in fiscal years 1996 - 1997. The construction work was started at the test site, the Wakamatsu Operations & General Management Office, and to manufacture the gasifier and other main facilities were also started in 1998. The operation tests are in progress since the construction work was completed at the end of June 2001. This paper describes the performance of IGFC using MCFC and gives the status of construction of a pilot plant.

Table 1 Development Schedule



2. Performance of IGMCFC (in 1995)

2.1 Outline of the System

The integrated coal gasification MCFC combined cycle (IGMCFC) is composed of a coal gasification unit, gas clean-up unit, MCFC unit, and power island, as shown in Figure 1.

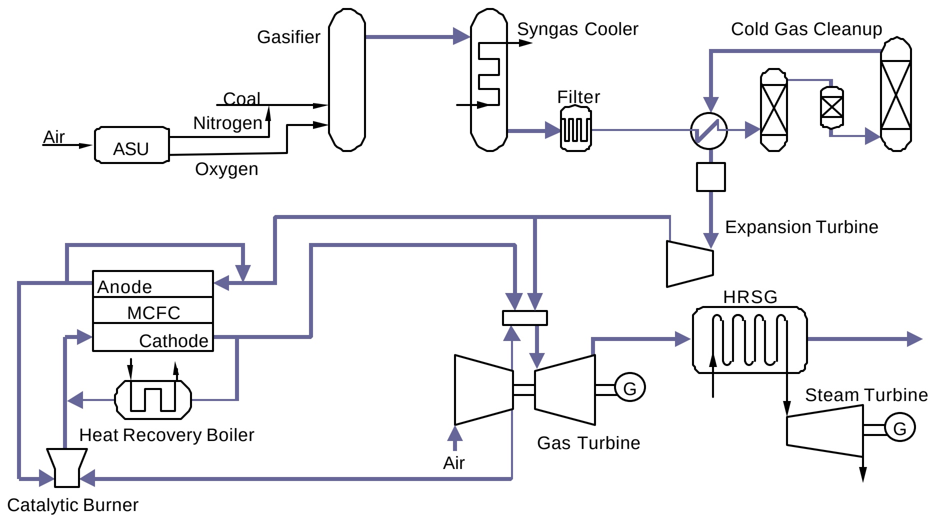


Figure 1 IGMCFC System Flow

Coal gasification

Pulverized coal is transported by nitrogen to the gasifier, where it reacts with a gasifying agent (95 percent oxygen) at 26.5 ata and is converted into a fuel gas. Meanwhile, molten ash is discharged from the bottom of the gasifier into a water quench. The high-temperature syngas exits the gasifier and is forwarded to a gas clean-up unit after heat is recovered by passing it through a syngas cooler, lowering it to 450°C. Char in the syngas is removed by a cyclone and filter, and recycled to the gasifier by the syngas.

Gas clean-up

Cold gas clean-up must be applied in order to meet the strict tolerance limits of fuel cells. Impurities such as halogens, sulfur and so on in the syngas are removed by a water scrubber and a methyldiethanolamine (MDEA) absorber, and the syngas is finely desulfurized by use of zinc oxide (ZnO). Acid gas removed by the MDEA absorber is burned in air in a furnace and the sulfur content is recovered as gypsum by use of limestone. Since the operating pressure of fuel cells is set at approximately 15 ata, to match that of the gas turbine, the pressure energy of the syngas is recovered as power through an expansion turbine.

Fuel cell (MCFC)

In coal gas, the CO concentration is high while the H_2 and H_2O concentrations are low. There is a possibility, therefore, that carbon will precipitate at the electrode through the following reaction and that cell performance will drop. Therefore, steam is added and the anode exhaust gas is recycled to the anode inlet in order to increase the H_2O and CO_2 concentrations at the anode inlet and prevent precipitation of carbon. The anode exhaust gas is burned in a catalytic burner. The CO_2 produced in the catalytic burner is supplied to the cathode. Meanwhile, the fuel cell is cooled down by recycling part of the cathode exhaust gas to the cathode inlet through a heat recovery boiler.

$$2\,CO \Leftrightarrow \underline{C} + CO_2$$
$$H_2 + CO \Leftrightarrow \underline{C} + H_2O$$

Power island

The cathode exhaust gas (700°C) is sent to the gas turbine and the gas turbine inlet temperature is increased to 1,300°C by adding the syngas. Heat is recovered from the gas turbine exhaust gas through a HRSG, and the generated steam is sent to the steam turbine (150 ata, 538/538°C) combined with steam generated at the gasification unit and the fuel cell unit.

2.2 Parameter Study

Conditions examined in the parameter study are shown in Table 2. The anode recycling gas ratio is defined as the ratio of the anode recycling gas volume to the syngas volume supplied to the MCFC. Results of examining oxygen concentration as the gasifying agent are indicated in Figures 2 and 3. Here, the oxygen concentration is adjusted by mixing 95 percent pure oxygen with air extracted from the gas turbine. In this study, the number of fuel cell stacks and the gas turbine inlet temperature are kept constant. Therefore, if the oxygen concentration falls, the calorific value of the syngas will be reduced, thereby increasing the fuel supply to the gas turbine. The coal supply will then increase accordingly. As a result, the gas turbine and steam turbine power output will increase even though the fuel cell power output is nearly constant. As has been discussed, because the power output ratio of the fuel cell is reduced as the oxygen concentration falls, the thermal efficiency is also reduced. In view of the foregoing, the oxygen concentration was set at 95 percent in this feasibility study. Optimization was similarly applied to other parameters.

Table 2 Conditions of Parameter Study

Parameter	Base case	Variation range
O_2 conc. In gasifying agent	95 vol%	21 - 95 vol%
Fuel utilization*1	80%	50 - 85 %
Oxidant utilization*1	20%	15 - 35 %
Anode recycling ratio	6.6	6.0 - 7.4

*1: Utilization with one pass is indicated

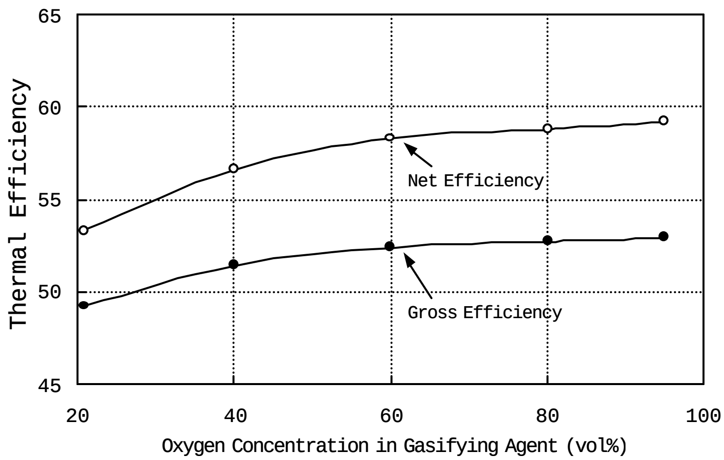


Figure 2 Effect of Oxygen Concentration on Thermal Efficiency

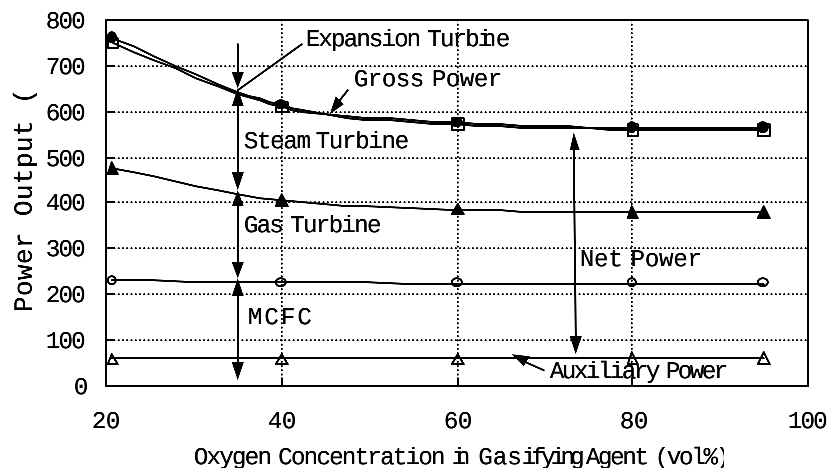


Figure 3 Effect of Oxygen Concentration on Power

2.3 Plant Performance

As a result of the parameter study, IGMCFC performance calculations were conducted after setting the following design conditions. Plant performance is shown in Table 4. The performance of the coal gasification MCFC combined cycle indicated that gross and net thermal efficiency would be 59.6 and 53.3 percent (HHV basis) respectively. It was clear that considerably higher efficiency could be obtained in comparison with a conventional coal-fired power plant.

Table 3 Design Conditions

Gas turbine inlet temperature	1,300°C
O_2 conc. in gasifying agent	95 vol%
Fuel utilization (one pass)	80%
Oxidant utilization (one pass)	25%
Anode recycling ratio	6.6

Table 4 IGMCFC Performance

Gross power output	616.6 MW
MCFC	261.8 MW
Gas turbine	152.2 MW
Steam turbine	199.5 MW
Auxiliary power	65.3 MW
Net power output	551.3 MW
Gross efficiency	59.6%
Auxiliary power ratio	10.6%
Net efficiency	53.5%

3. Detail Design of Pilot Plant (in 1997)

In this project, a pilot plant with a coal capacity of 150 tons per day has installed at Wakamatsu. It will be used for verification of the total coal gasification system for fuel cells. Figure 4 shows the overall system flow and Table 5 shows the specifications of the main equipment.

Table 5 EAGLE Pilot Plant Specifications

Coal gasification	Oxygen-blown entrained-flow gasifier (two-stage tangential flow type)
Coal feed	150 tons per day
Gasification pressure	26.5 ata
Gas clean-up	Cold gas clean-up using MDEA
Syngas volume	14,600 m^3 N/h (MDEA absorber outlet)
Sulfur recovery	Limestone-gypsum wet scrubbing
Air separation	Pressurized cryogenic separation
Oxygen production	4,300 m^3 N/h
Oxygen concentration	95 vol%
Air feed	20,000 m^3 N/h
Air feed pressure	13 ata
Gas turbine power	8,000 kW

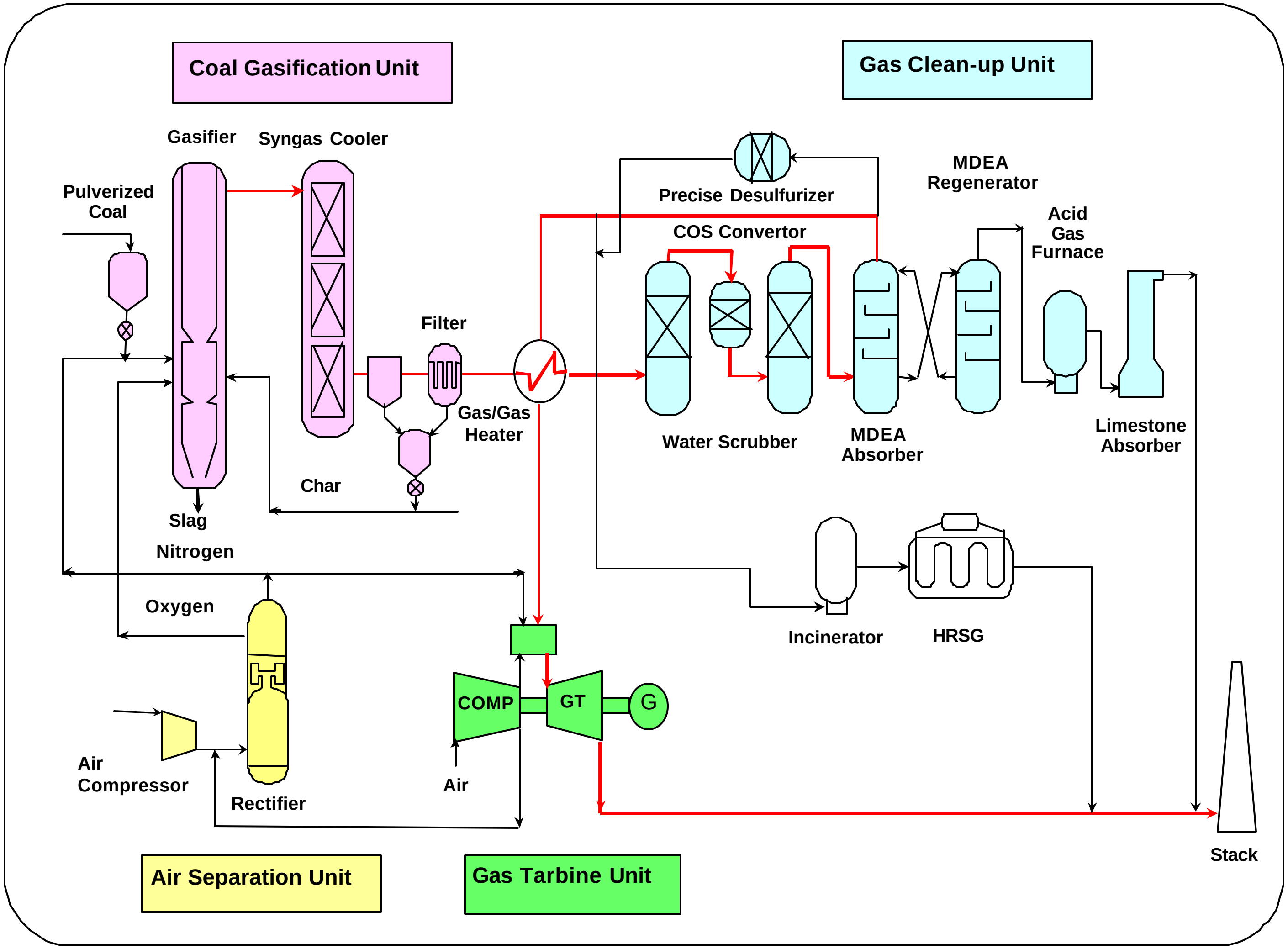


Figure 4 Flow Diagram of The EAGLE Pilot Plant

Coal gasification

High concentrations of H_2 and CO and a high calorific value for the syngas are suitable in application of a gasifier for use with fuel cells. This project has thus employed a dry feed oxygen-brown entrained-flow gasifier. Coal is transported by nitrogen from the upper and lower burners into the gasifier in a tangential flow pattern. Oxygen (the gasification agent) is supplied to each stage. By optimizing the distribution of coal supply to the upper and lower stages and the oxygen ratio of each stage, it is possible to obtain both high gasification efficiency and stable operation. The syngas recycled from the outlet of the water scrubber is supplied to the outlet of the gasifier in order to quench slag particles. Char contained in the syngas is removed by a cyclone and a filter, and recycled into the lower stage of the gasifier by N_2 gas. The gasifier enables steam to be injected from the lower stage to reduce oxygen consumption.

Gas clean-up

This project employs cold gas clean-up in order to satisfy the tolerance limits of fuel cells. Syngas at a temperature of approximately 400°C exits from the filter and is heat-exchanged at the Gas/Gas Heater (GGH). Impurities such as halogens and ammonium are removed in a water scrubber, and the gas is then desulfurized in an absorber. Here, this project employs methyldiethanolamine (MDEA) as the sorbent. Since MDEA has low absorptivity for carbonyl sulfide (COS), COS must be converted into H_2S in a COS converter in advance. The clean syngas, which exits the MDEA absorber at approximately 40°C, is heated to approximately 200°C by a steam heater and GGH and supplied to the gas turbine. Part of the clean syngas is sent to the precise desulfurizer, where it is further desulfurized down to the tolerance limit of the fuel cell or below.

Gas turbine and air separation

The gas turbine and generator are driven by burning clean syngas in combusters. This supplies auxiliary power for the pilot plant. It is also designed so that air extracted from the gas turbine is supplied to the air separation unit. Thus pressurized cryogenic separation is employed for air separation. Surplus nitrogen in the air separation unit is supplied to the gas turbine to reduce NOx.

4. Construction of Pilot Plant

At the test site, the Wakamatsu Operations & General Management Office, Electric Power Development Co., Ltd. in Fukuoka Prefecture, the mechanical foundation work was started in August 1998 for the main facilities of the pilot plant, that is, the coal gasification and gas clean-up units. The building foundation work and the steel frame construction were also started for the operation and compressor rooms. The gasifier and the syngas cooler were unloaded in September 1999 (figure 5). The operation tests have been conducted, since the construction work was completed at the end of June 2001, as shown in Figure 6. Figure 7 describes the image of the EAGLE pilot plant. It is scheduled to carry out the running study until June 2006.

Figure 5 Unloaded Gasifier

Figure 6 EAGLE gasifier

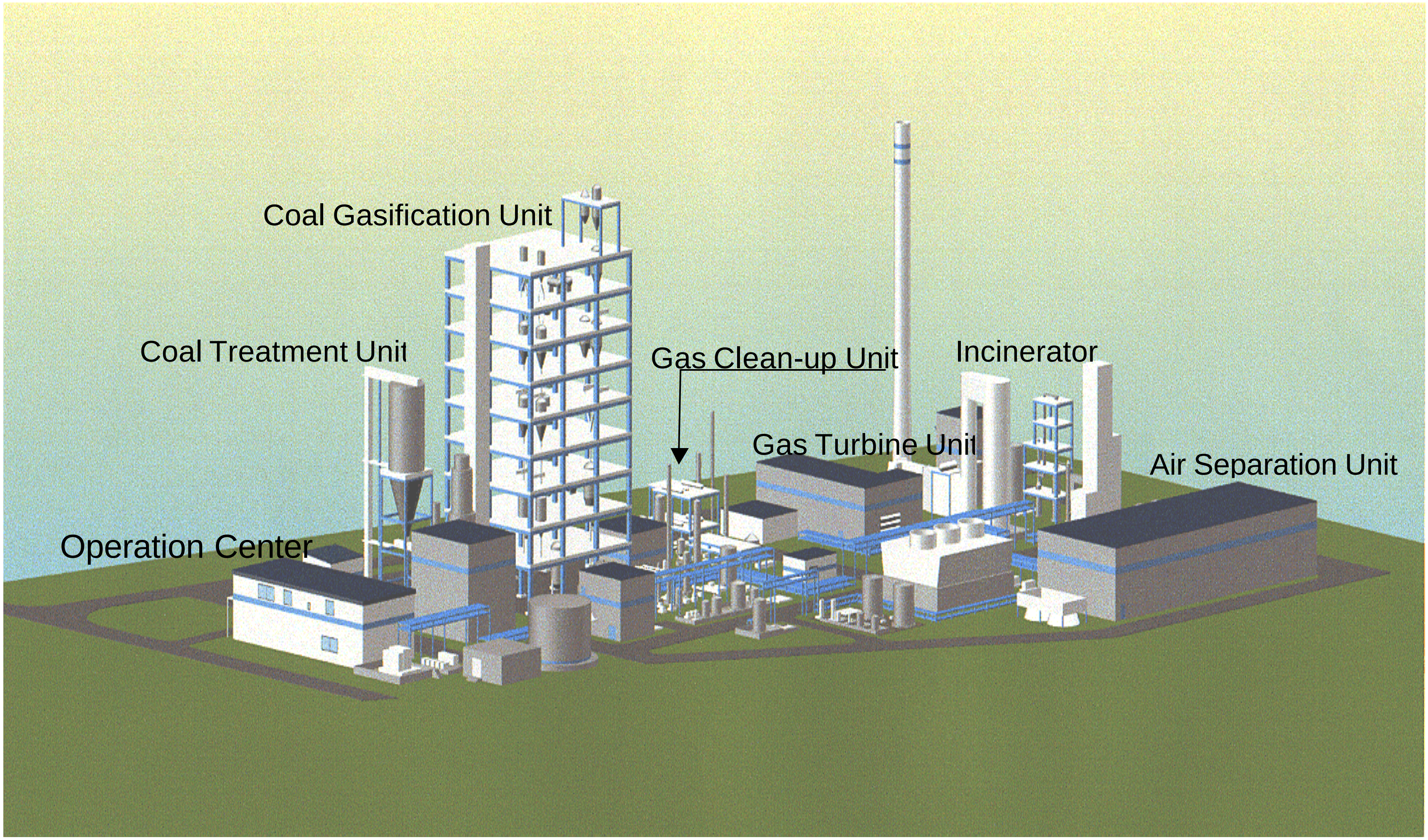


Figure 7 Image of EAGLE Pilot Plant

5. <Informative> Development Status for Fuel Cells

In a Japanese national project for development of commercial fuel cells, a 1,000 kW (250 kW $\times$ 4 u) pilot plant for “Molten Carbonate Fuel Cells (MCFC)” is being promoted at the Kawagoe Thermal Power Station, Chubu Electric Power Co., Inc. in Nagoya. The equipment installation was completed. It has been worked after adjusting each of the systems.

Electric Power Development Co., Ltd. is promoting the self-development of “Solid Oxide Fuel Cells (SOFC)” in collaboration with Mitsubishi Heavy Industries, Ltd. We have developed the atmospheric 1 kW SOFC module, the atmospheric 10 kW module, and the pressurized 1 kW module one after another. In December 1998, we succeeded in the continuous 7,000-hour power generation with the pressurized 10 kW SOFC module, leading the world. The test runs of the modified pressurized 10 kW module have been conducted in order to verify one of the important subjects to establish the 100 kW module, “Fuel internal-reforming technology”.

The EAGLE project contains the “Precise Desulfurizer” for fuel cells. When the test run gets started and the coal gasification gas supply becomes available in 2002, the demonstration test will be proposed for the “Integrated Coal Gasification Fuel Cell Combined-cycle Power Generation System (IGFC)”, depending on the status of development for MCFC and SOFC technologies. It can be said that the coal utilizing ultra-high efficiency power generation technology will be realized soon.

6. Summary

As a result of a feasibility study of the integrated coal gasification MCFC combined cycle, we demonstrated that an oxygen-blown gasifier would be suitable for IGFC, and that the net thermal efficiency of IGMCFC would be 53 percent or more. A pilot plant with a capacity of 150 tons per day will be equipped with a coal gasification unit, gas clean-up unit, air separation unit, and gas turbine unit (outside the range of the subsidy). It is now possible to implement experiments on a total coal gasification system for fuel cells. Operation commenced in July 2001. We look forward to obtaining results in which coal gasification technology for fuel cells is put into practical use. This project is being conducted as a national project by our company entrusted by the New Energy Industrial Technology Development Organization (NEDO). We would like to express our deep appreciation for the support and guidance we have received from all concerned parties, including the Agency of Natural Resources and Energy of METI.

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IGFC (EAGLE Project)

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Electric Power Development Co., Ltd.

Presentation Overview

1) Background and Objectives

2) Project Schedule

3) Feasibility Study on IGFC

4) Features of Gasifier

5) Outline of Pilot Plant

Background

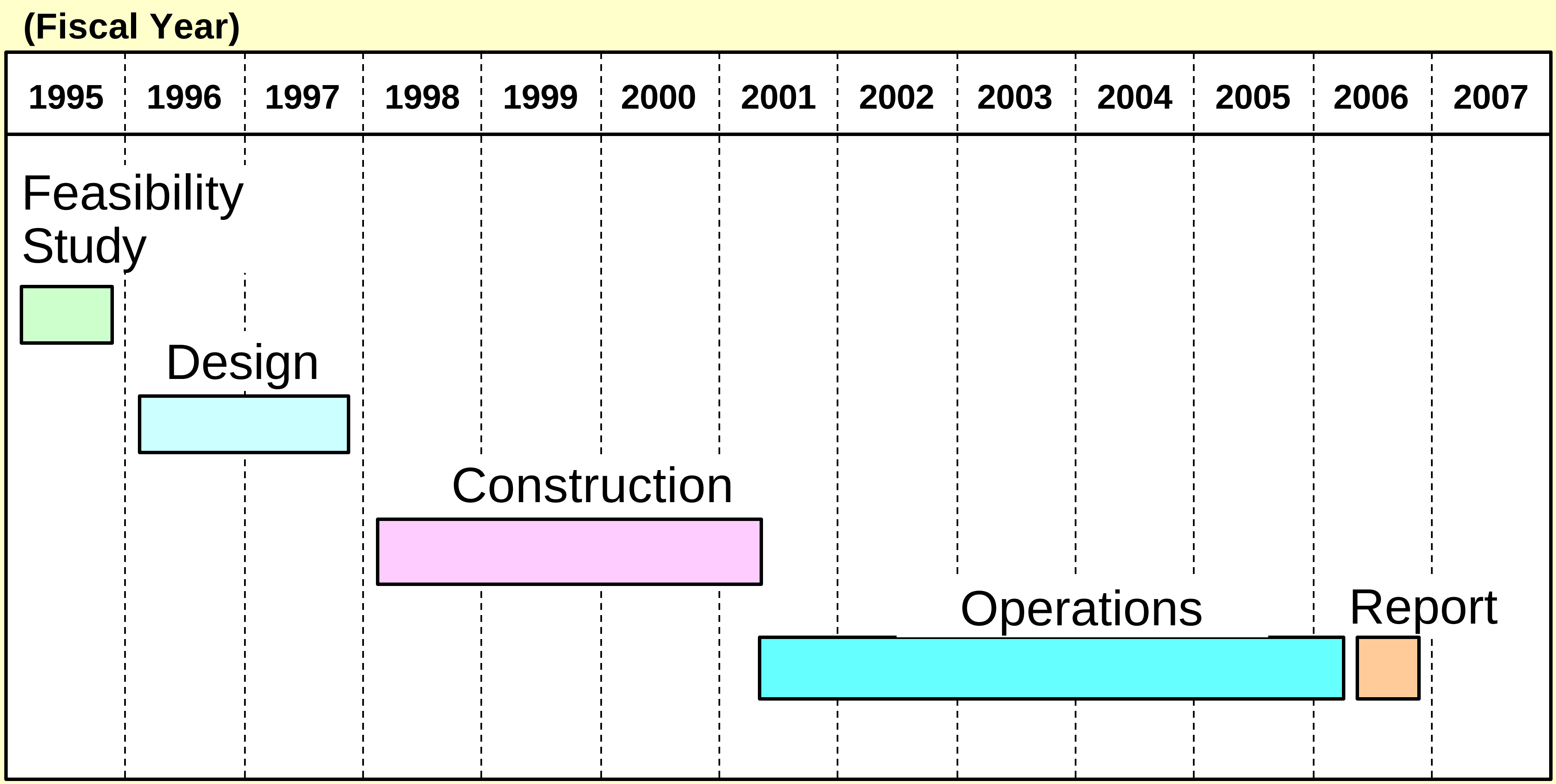
Coal is an important energy resource since it has abundant reserves worldwide and its price is more stable than other fossil fuels (oil and natural gas). However, CO_2 emissions from coal are higher than with other fossil fuels. Thus we are promoting development of an Integrated coal Gasification Fuel Cell combined cycle (IGFC) as a coal-based high-efficiency power generation technology.

Objectives

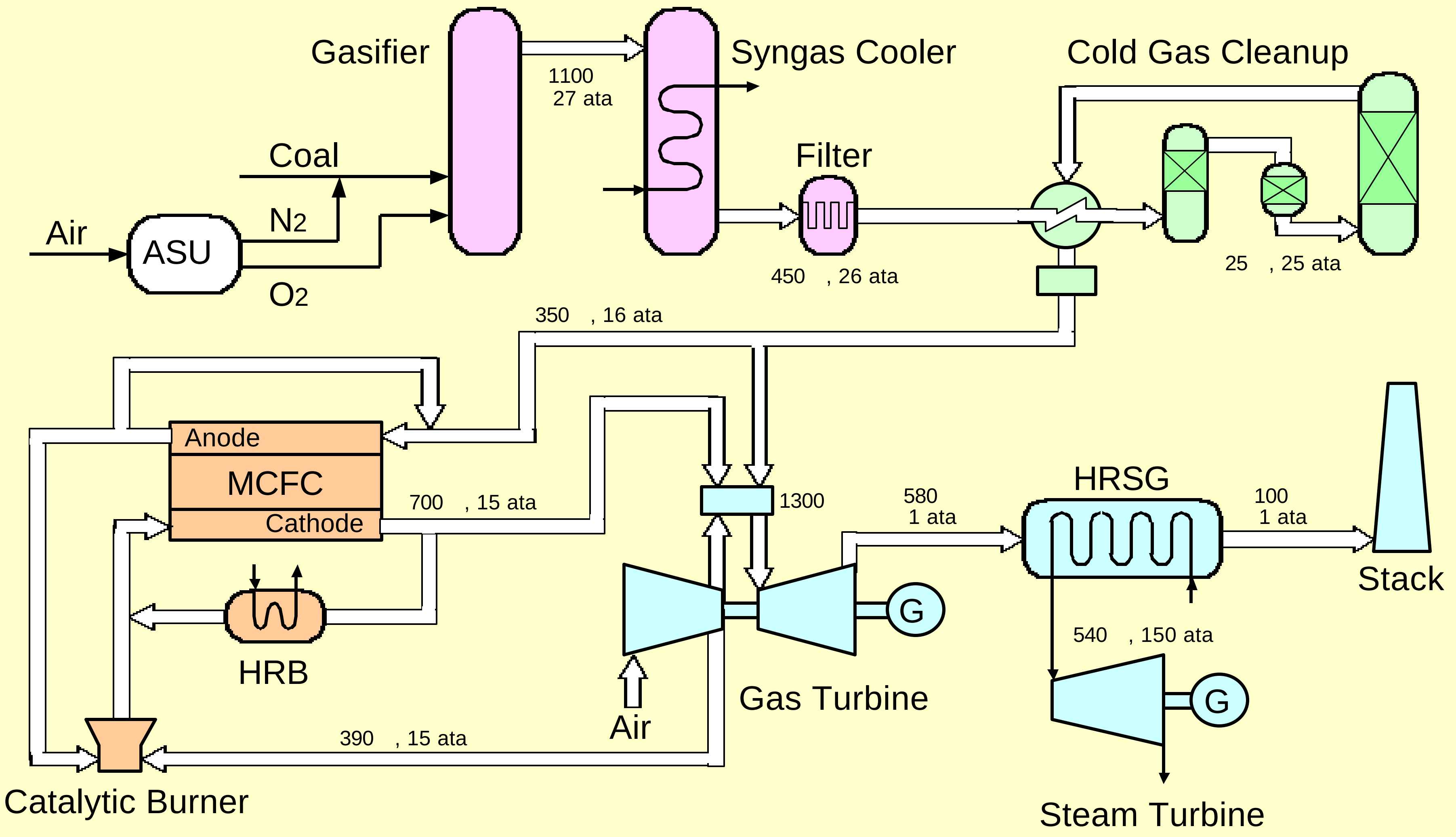
(1) Development of oxygen-blown entrained-flow gasifier

(2) Establishment of gas cleanup technology for fuel cells

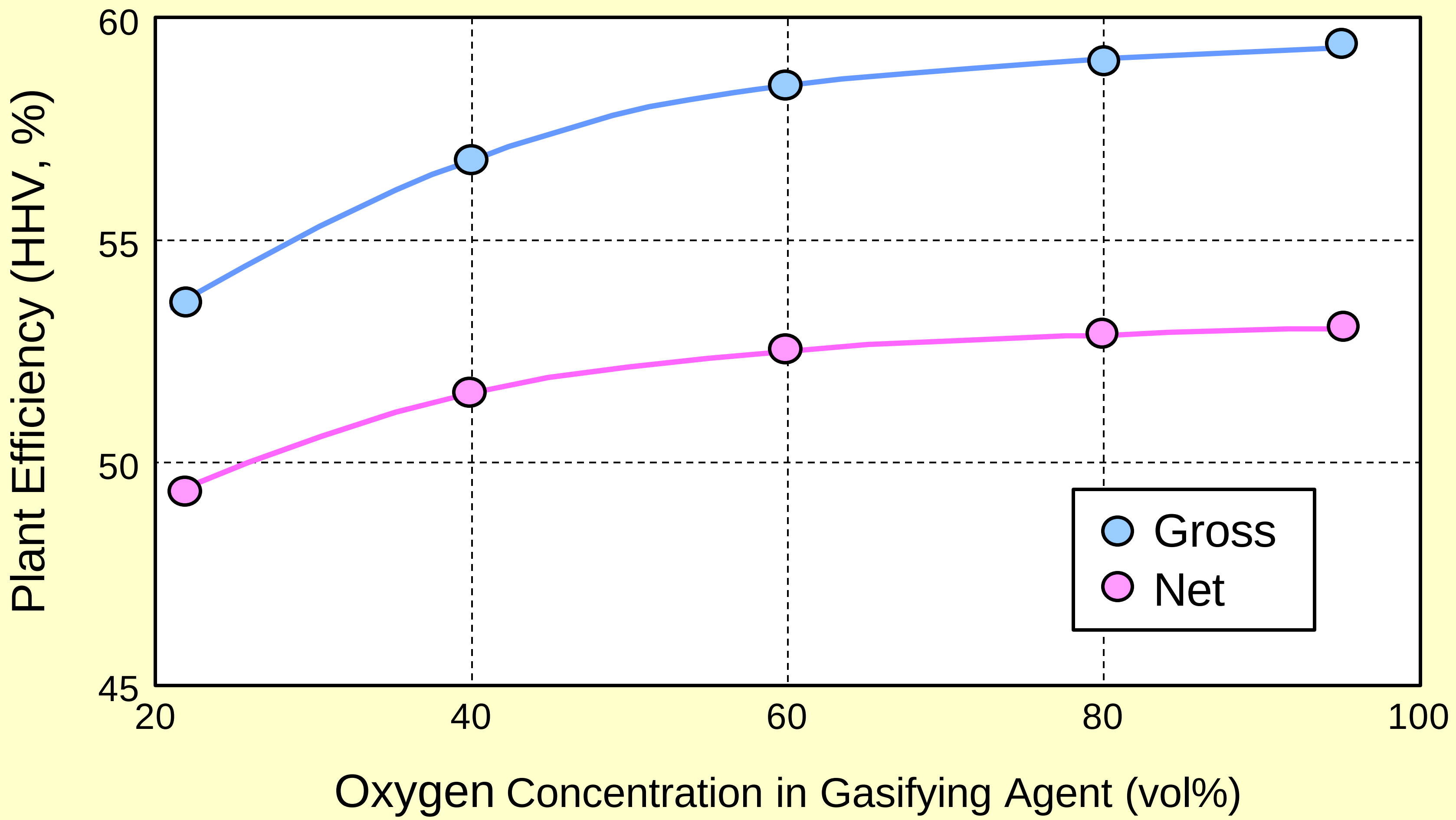
EAGLE Project Schedule



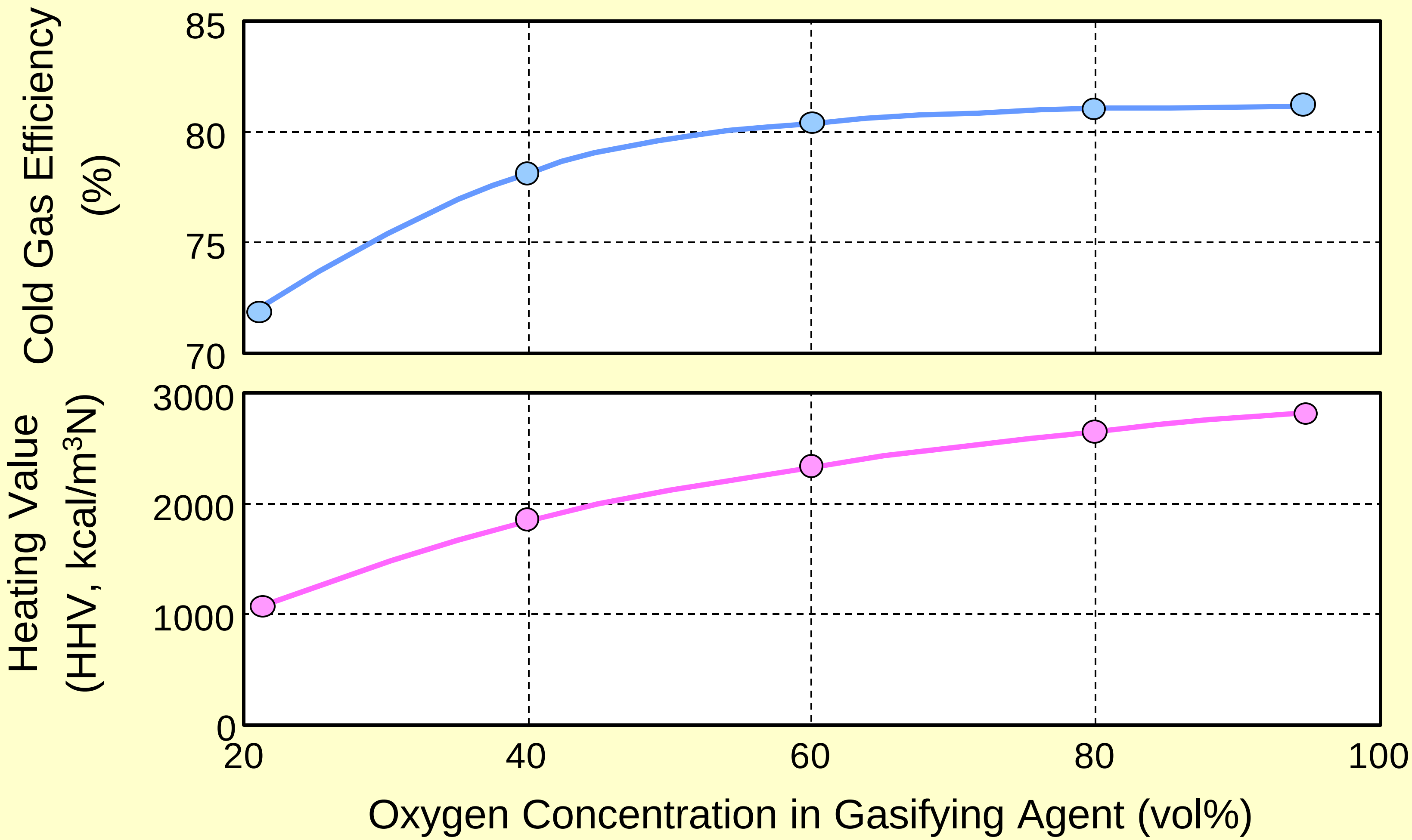
Integrated Coal Gasification Fuel Cell System with MCFC



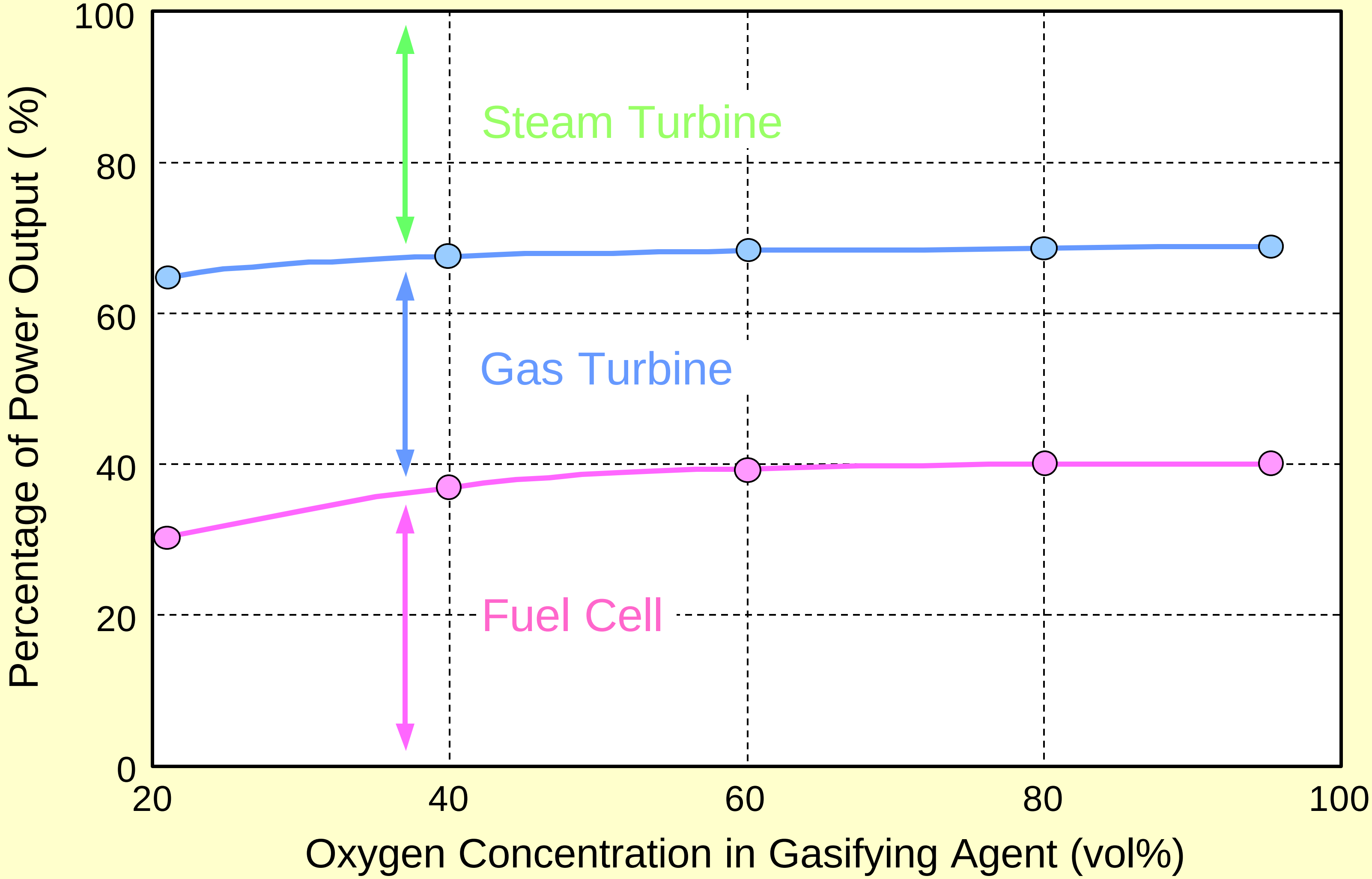
Effect of Oxygen Concentration on IGFC Efficiency



Gasification Efficiency and Heating Value of Syngas



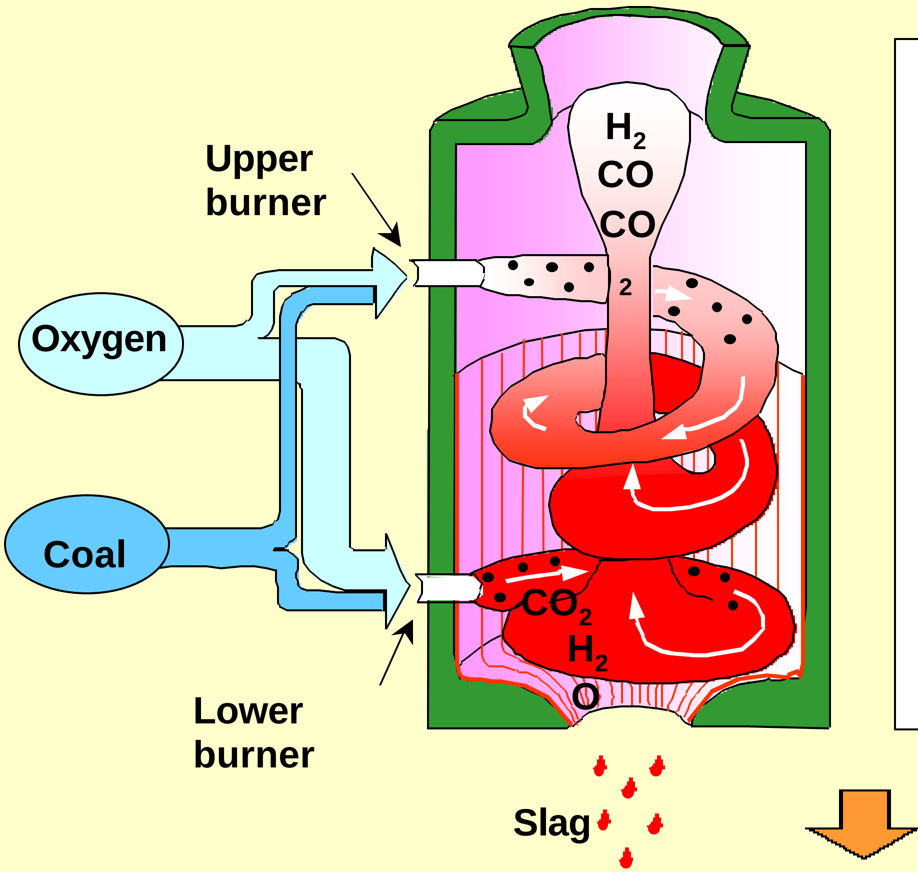
Power Output of IGFC

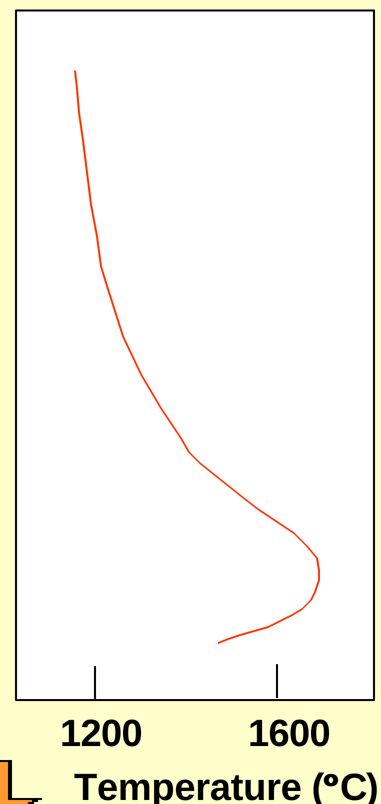


IGMCFC Performance

Gross power output	616.6MW
MCFC	261.8 MW
Gas turbine	152.2MW
Steam turbine	199.5MW
Auxiliary power	65.3MW
Net power output	551.3MW
Gross efficiency	59.6%
Auxiliary power ratio	10.6%
Net efficiency	53.3%

Features of EAGLE Gasifier





Upper: **Lean oxygen**

Coal®Char

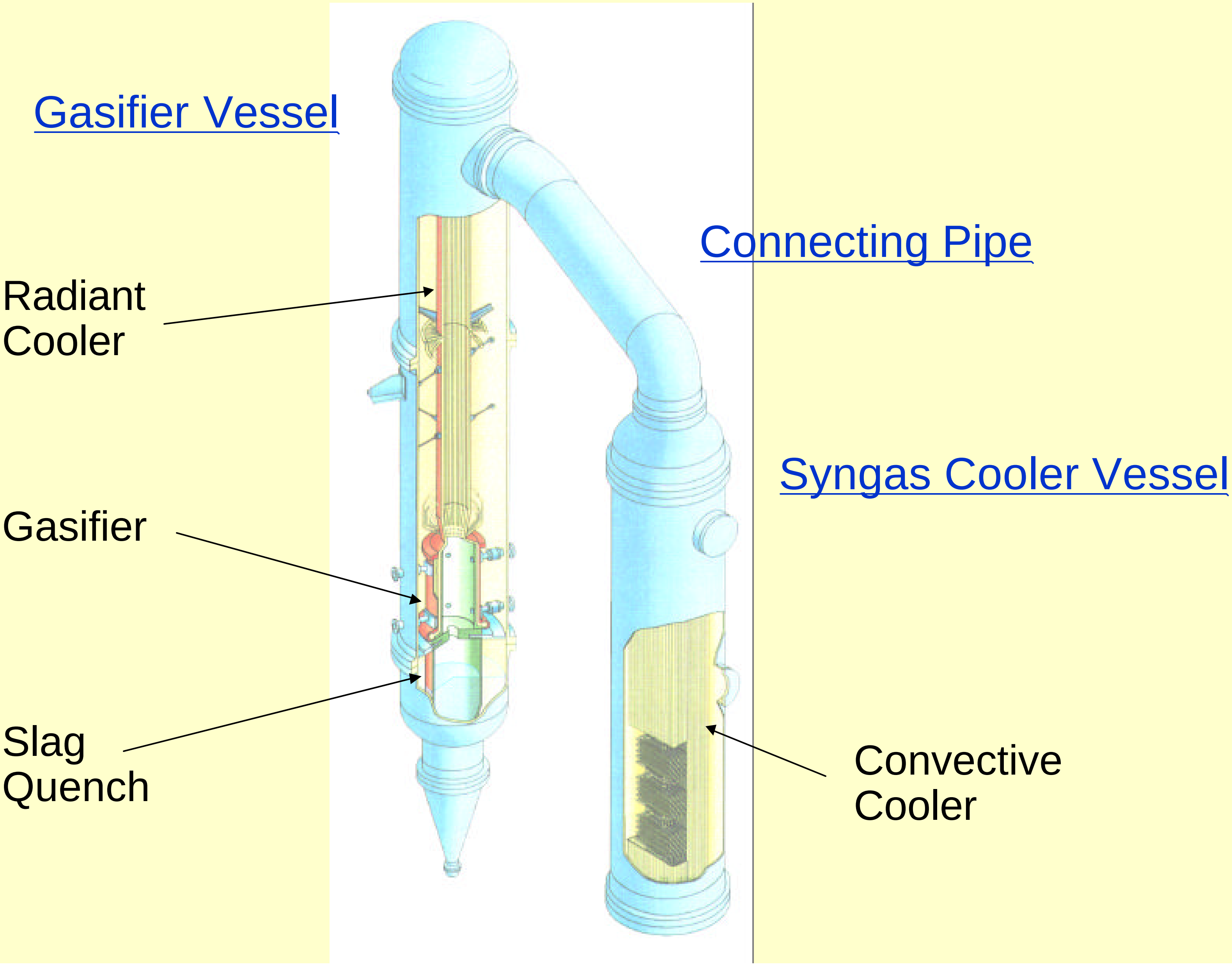
Char+CO_2+H_2O®CO+H_2

Lower: **Rich oxygen**

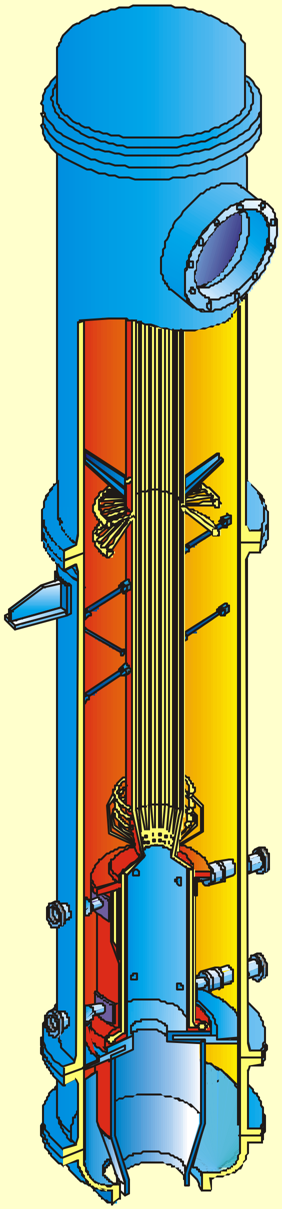
Coal+O_2®CO_2+H_2O

High-efficiency gasification
Stable slag discharge

Cutaway of the EAGLE Gasifier

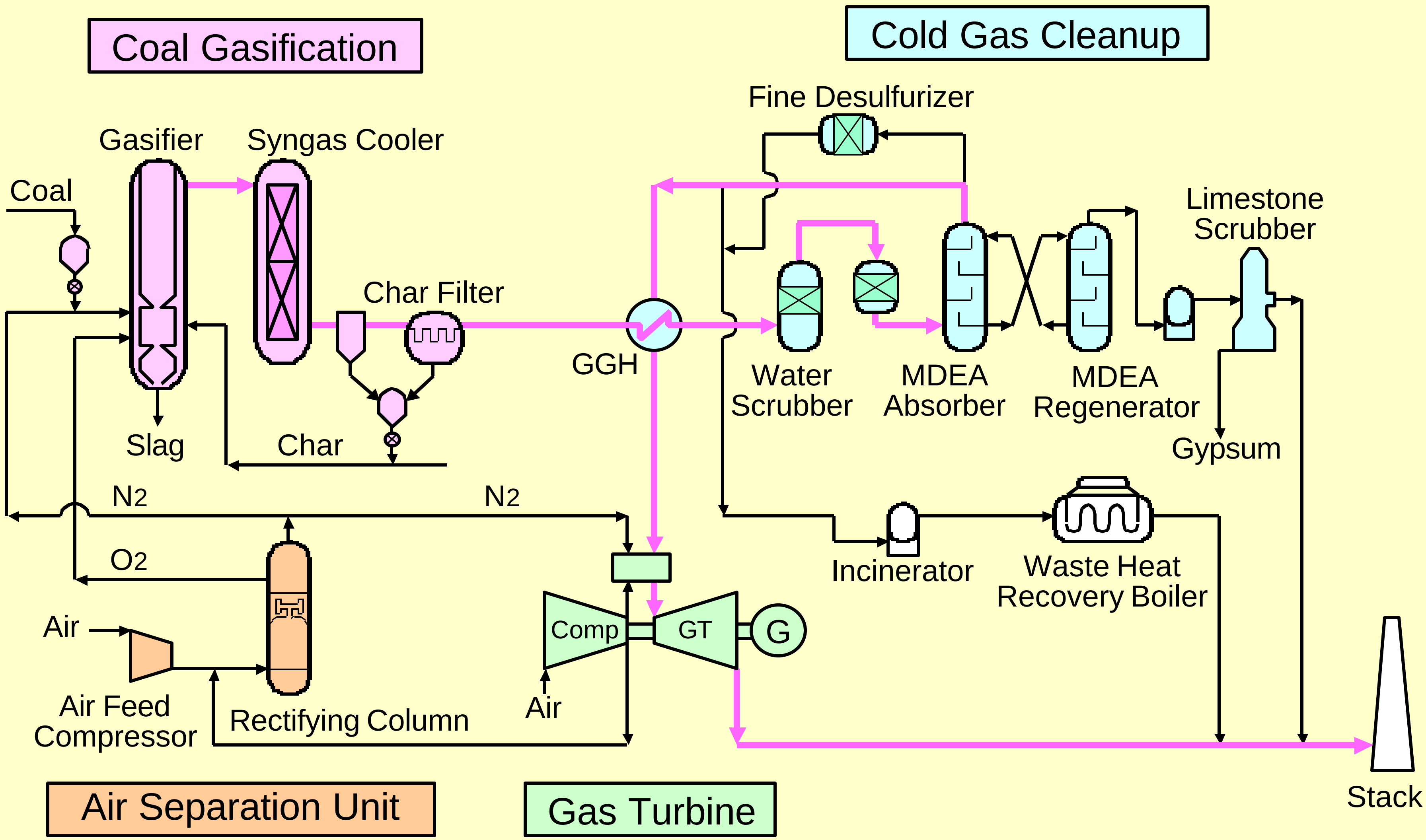


EAGLE Gasifier



Coal Feed Rate	150 tons per day
Inner Diameter of the Gasifier	1000 mm
Inner Diameter of the Gasifier Outlet	500 mm
Inner Diameter of the Radiant Cooler	738 mm
Number of Upper Burners	4
Number of Lower Burners	4
Number of Char Burners	2
Number of Steam Nozzles	2
Height of the Pressure Vessel	21 m

Flow Diagram of the EAGLE Pilot Plant



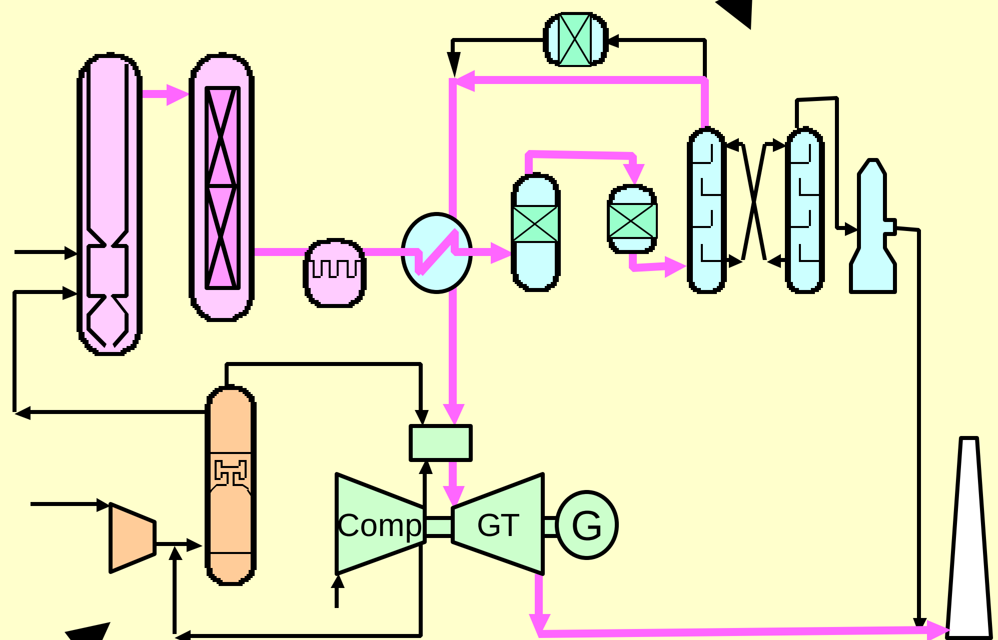
Specifications of the EAGLE Pilot Plant

Coal Gasifier	Oxygen-blown Two-stage Entrained-flow
Coal Feed Rate	150 tons per day
Gasification Pressure	26.5 ata
Syngas Composition	CO 53 %, N_2 20 %
	H_2 21 %, Ar 1 %
	CO_2 3 %, H_2S 1200 ppm
	H_2O 2 %, COS 100 ppm
Cleanup System	Cold Cleanup Using Methyldiethanol Amine
Syngas Flow	14,800 m^3N/h (MDEA Absorber Outlet)
Sulfur Compounds	< 50 ppm (MDEA Absorber Outlet)
	< 1 ppm (Fine Desulfurizer Outlet)
Sulfur Recovery Unit	Limestone Wet Scrubbing
Air Separation Unit	Pressurized Cryogenic Separation
Air Feed Rate	25,700 m^3N/h
Feed Air Pressure	12 ata
Oxygen Production	4,300 m^3N/h
Oxygen Purity	95.0 vol%

Testing Items at the EAGLE Pilot Plant

Cold Gas Cleanup
COS Catalyst Characteristics
Degradation of MDEA
Behavior of Trace Elements

Coal Gasification
Oxygen Ratio
Quench Gas Volume
Steam Injection
Corrosion in Syngas Cooler
Char Filter



Air Separation Unit
Pressurized ASU
Air Integration with Gas Turbine
Load Following Characteristics